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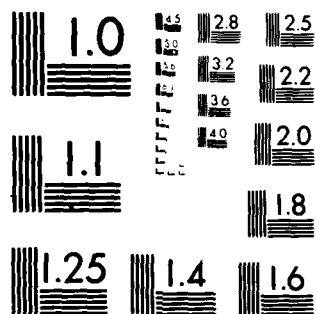
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Development of a Low Data Rate Repeater

HANS LAPING

30 January 1981

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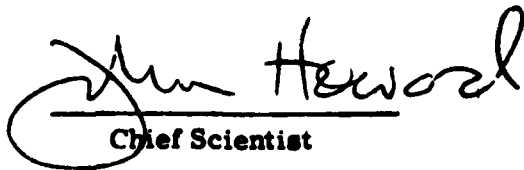
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FOR THE COMMANDER

Chief Scientist

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report describes a 40 MHz to S-Band data repeater developed to increase the radio horizon for high altitude scientific balloon flights launched from Holloman AFB in New Mexico.

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Preface

I would like to thank R. Ganion who breadboarded, tested, and built the repeater, and also C. Rice who provided many helpful suggestions in editing this report.

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Tables

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Illustrations

Development of a Low Data Rate Repeater

1. INTRODUCTION

This report describes a 40 MHz to S-Band data repeater developed under
In-House Work Unit 76591203. The intent of this data repeater is to increase
the range of radio signal reception from high altitude scientific balloon flights
launched from Holloman AFB in New Mexico. Holloman AFB is located in a
valley between two mountain ranges that limit the line of sight of radio signals
to the east and west. The optical line-of-sight obstruction to the east is between
two and three degrees, and to the west between one and two degrees. What
aggravates the situation even more is the fact that Holloman AFB is 4,000 ft
above sea level with the line-of-sight obstructions indicated above.

2. OPTICAL LINE-OF-SIGHT

A few simple calculations will show what effect the line-of-sight obstructions
have on the optical horizon. Figure 1 depicts the geometry used in the calcula-
tions that provide the line-of-sight (LOS) distance for various angles of obstruc-
tion. The calculations are based on the law of sines and cosines.

H = LOCATION OF HOLLOMAN AFB
R = LOCATION OF REPEATER
B, B' = LOCATIONS OF BALLOON
S = SURFACE OF EARTH
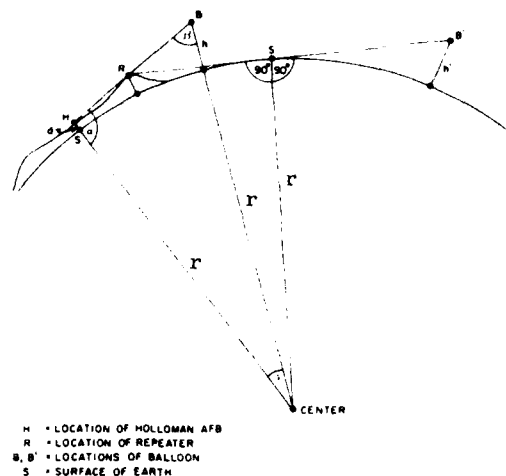
Figure 1. Geometry Used for Calculations of Optical Horizon

$$\frac{a}{\sin \alpha} = \frac{b}{\sin \beta} = \frac{c}{\sin v} \qquad \text{(law of sines)} \qquad (2\text{-}1)$$

$$c^2 = a^2 + b^2 - 2ab \cos v \text{ (law of cosines)} \qquad (2\text{-}2)$$

$$\alpha + \beta + v = 180°, \text{ for any triangle} \qquad (2\text{-}3)$$

$$a = r + h$$

$$b = r + d$$

$$c = LOS$$

$$r = 3963 \text{ mi (radius of earth)}$$

$$d = 4000 \text{ ft (elevation of Holloman AFB)}$$

$$h = 10K \text{ ft plus } 10K \text{ ft increments up to } 150K \text{ ft (balloon altitude).}$$

The angle α is 90° for zero obstructions and 93° for an obstruction angle of 3 .
If α is 90°, then v is calculated, as shown below, for a balloon altitude of
10,000 ft.

$$\frac{a}{\sin 90°} = \frac{r + h}{\sin 90°} = \frac{b}{\sin \beta} = \frac{r + d}{\sin \beta}$$

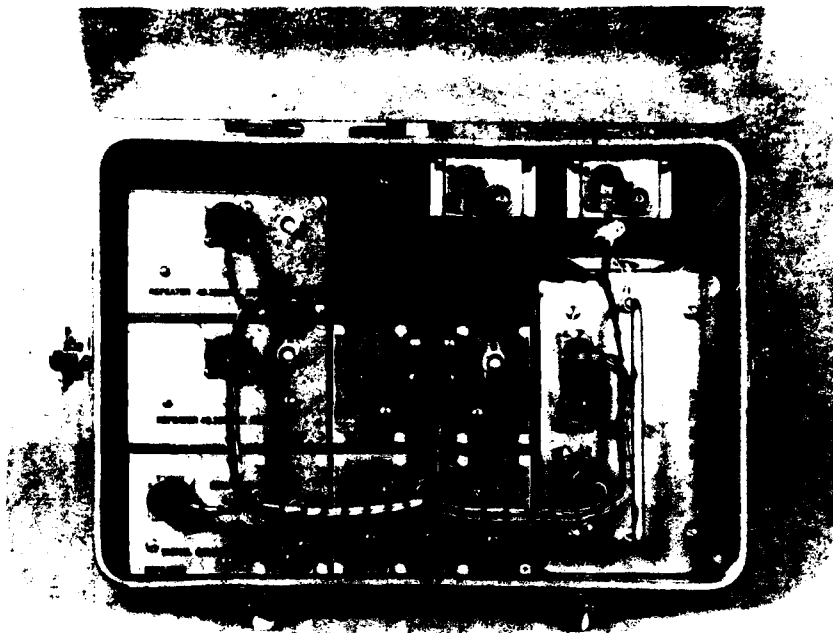$$\sin \beta = \frac{r + d}{r + h} = \frac{3963 + .757575}{3963 + 1.8939349}$$
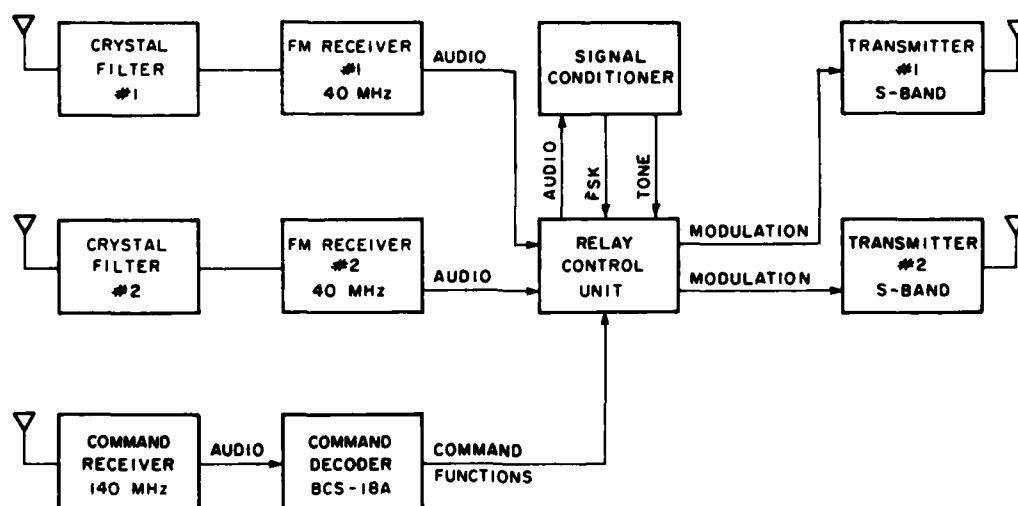
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Figure 2. Data Repeater

Figure 3. Block Diagram of Repeater

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$$\beta = \sin^{-1} .999713 = 88.6282°$$
$$\gamma = 180° - \alpha - \beta = 180° - 90° - 88.6282° = 1.3718°$$
$$c = LOS = (a^2 + b^2 - 2ab \cos \gamma)^{1/2}$$
$$c = [(r + h)^2 + (r + d)^2 - 2(r + h)(r + d) \cos 1.3718°]^{1/2}$$
$$c = 94.92 \text{ miles}$$

Table 1 shows the line-of-sight distances for various balloon altitudes and obstruction or elevation angles for Holloman AFB calculated by the above method.

Table 1. Optical Horizon or LOS at Holloman AFB*

Elevation Angle	Line of Sight				Balloon Altitude
	0°	1°	2°	3°	
	95	48	29	21 miles	10K ft
	155	101	69	52	20
	198	140	103	79	30
	233	173	132	104	40
	263	203	159	127	50
	290	229	183	149	60
	315	253	206	170	70
	338	276	227	189	80
	360	297	247	208	90
	380	317	266	226	100
	399	336	284	243	110
	418	354	302	259	120
	436	372	319	275	130
	453	389	335	290	140
	469	405	351	305	150

*rounded off to nearest mile

Table 2 is generated in a similar manner, but for an observation point at sea level. Due to diffraction of radio waves in the very high frequency (VHF) band, the optical line of sight (no diffraction) and the reception range of radio signals are not the same. On the average, the diffraction of radio waves increases the line of sight, which can be calculated by assuming an earth radius of 4/3r. For this assumption, a good approximation for the line-of-sight distance (in miles) of radio waves is $(2h)^{1/2}$ for an elevation angle of 0° and a balloon altitude of h ft. The diffraction of radio waves changes continuously due to weather conditions and many other factors; therefore, the line-of-sight table for Holloman can be used as a minimum to estimate how far a balloon can travel before the radio signals are lost at Holloman AFB.

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Table 2. Optical Horizon at Sea Level*

Elevation Angle	Line of Sight				Balloon Altitude
	0°	1°	2°	3°	
	123	72	47	34 miles	10K ft
	173	117	83	63	20
	212	154	115	89	30
	245	186	143	114	40
	274	214	169	136	50
	300	239	192	158	60
	324	263	214	178	70
	347	285	235	197	80
	368	305	255	215	90
	388	325	274	232	100
	407	244	291	249	110
	425	361	309	266	120
	442	379	325	281	130
	459	395	341	297	140
	475	411	357	311	150

*In statute miles

If a radio repeater is used and located on top of a mountain peak, the line of sight will increase because negative elevation angles can be included in the calculations for the line-of-sight distances.

As an example, let us assume that a radio repeater is placed on a mountain peak at 10,000 ft. If there is no obstruction around the receiving antenna between elevation angles of 0° and -1.771°*, then from Figure 1, the line-of-sight distance RB^1 is calculated by adding RS, which is equal to the LOS for a balloon altitude of 10,000 ft, to SB^1, the LOS of the actual balloon altitude from Table 2 (for 0° elevation). Let us now consider the LOS difference from Holloman AFB and a repeater station at 10,000 ft above sea level. For this comparison, let us further assume that a balloon floats at an altitude of 60,000 ft to the east of Holloman AFB where the obstruction angle is 3°. From Table 1, the LOS for 60,000 ft and an elevation angle of 3° is 149 miles. For the repeater station, the LOS for 10,000 ft at an elevation angle of 0° is 123 miles, and the LOS for 60,000 ft at an elevation angle of 0° is 300 miles. Adding these two distances provides an LOS of 423 miles for the repeater station, compared to 149 miles from Holloman. This comparison shows the great improvement of the LOS for the repeater, and also provides an input to the decision-making process of whether to deploy a communications van for short- and medium-range balloon flights.

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*This angle was calculated by using Figure 1, where d equals zero, h equals 10,000 ft, α equals 90°, and the elevation angle equals β minus 90°.

White Sands Missile Range operates several microwave relay stations at various mountain peaks around Holloman AFB. One such station is at Alamo Peak, and another is at Atom Peak. Both mountain peaks provide line of sight to our ground station at Holloman AFB. Both sites are manned, and AC power and telephone are also available; therefore, the permanent location of the repeater will be installed at one of these sites. Both peaks have an elevation of about 10,000 ft above sea level.

The concept of the repeater was tested during two balloon flights. The repeater was set up at Sacramento Peak. The radio signals from the balloon were received at Sacramento Peak and retransmitted to our ground station at Holloman AFB. The direct radio signals from the balloon at Holloman were lost long before the repeated signals from Sacramento Peak. Sacramento Peak is not one of the optimum locations for a repeater station because there are some obstructions towards the east; however, even this site improves the radio reception capability over our ground station at Holloman AFB.

3. TECHNICAL DESCRIPTION OF REPEATER

Figure 2 shows the physical components used in the repeater. All modules of the repeater are housed in a protective aluminum case. Each module will be described individually. The overall block diagram of the repeater is depicted in Figure 3. Only the control and signal lines are shown. The power supply is not included in the block diagram, but the power supply with its battery backup system always supplies power to the command receiver, the command decoder, and the relay control unit. Before any balloon flight, the mode of operation of the repeater is determined by the sequence of commands issued from ground control at Holloman AFB. The details of the operational mode of the repeater will be described when the command control functions are described in detail with the description of the individual modules.

The repeater receives the frequency-modulated radio signals from the balloon at 40 MHz, then either FM receiver #1 or #2 demodulates the information and feeds the relay control unit, which then supplies the modulation to either #1 or #2 of the repeater transmitters. This mode of operation bypasses the signal conditioner.

Two other modes of operation can be selected by radio command via the command receiver, the command decoder, and the relay control unit. In one mode, the demodulated information signals from the balloon switch a single tone (3107 Hz) on or off according to the information generated by the balloon's digital encoder. In the other mode, the same information frequency-shifts (FSK) an

audio oscillator between 2025 Hz and 2225 Hz. In order to minimize transmission of noise, both the single tone and the FSK signal can be filtered by the signal-conditioning unit, and then applied to the modulation input to one of the transmitters. Because the information from the balloon is transmitted via very high frequency (VHF) radio link, the modulation frequency is limited to 3 KHz; therefore, this repeater can only be utilized for relatively slow data rates.

4. DESCRIPTION OF INDIVIDUAL MODULES

This section describes all the component modules that are used in the data repeater.

4.1 Transmitters

To provide redundancy and flexibility in the operation of the repeater, two identical transmitters are available for retransmission of data. Each transmitter delivers an output power of at least 2 W in the S-band (2200 MHz-2300 MHz) frequency spectrum. The input power requirement is 28 V ± 4 V at approximately .8A. The transmitter is model CTS-702, manufactured by Conic Corporation. Other pertinent technical specifications are provided in Conic's technical bulletin for telemetry transmitter CTS-702.

4.2 40 MHz FM Receiver

Figure 4 shows the internal construction of one of the 40 MHz data receivers. The receiver is model 810-056-03 manufactured by Repco Inc. This receiver is delivered as individual circuit modules mounted on a printed circuit board. Each circuit module plugs into a socket provided on the printed circuit board. Technical details are given in the receiver manual. [1]

We modified and added a few components to make it more suitable for this application. The receiver discriminator has two outputs; one output is filtered and provides a 6 db roll-off, and the other output is not filtered. We chose the second output and installed an RC filter which does not attenuate the 3100 Hz signal used by the balloon control and data package. In addition, we included a fuse, a reverse polarity protection diode and a 12 V regulator so that the receiver can operate with an input voltage of 28 V, the same as the S-band transmitters and also the rest of the repeater components. The receivers are mounted on a

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1. Instruction Manual, IB-42-30-016, RF Link Devices, Receiver Unit 810-056, Repco, Inc., Orlando, FL.

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chassis which slides into a cast aluminum box. This provides protection and
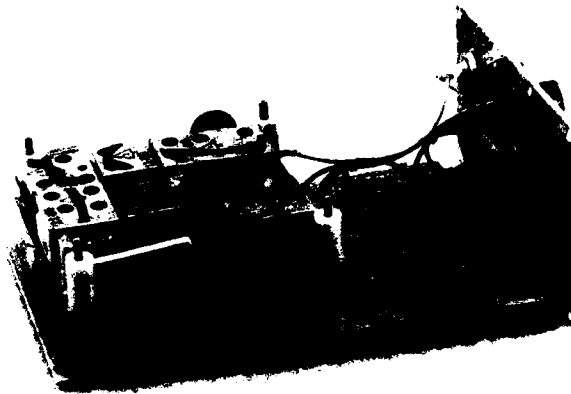RF shielding for the receiver.

Figure 4. 40 MHz Data Receiver

4.3 140 MHz FM Command Receiver

Figures 5a and 5b show the internal construction of the command receiver.
This receiver comes from the same family of modular component receivers as
the 40 MHz receiver described previously. It is also manufactured by Repco
Inc. Technical details are given in the technical manual for the receiver.[2]

A 1A fuse, a reverse polarity protection diode, and a 12 V regulator were
added to the receiver circuits. Also included is a circuit board with active
filters, and automatic gain control circuits that filter and limit the amplitude of
the audio output from the command receiver to the command decoder. The ampli-
tude of the audio output is controlled on an rms basis rather than by peak ampli-
tudes. This arrangement is more advantageous in a command system when
more than one audio frequency tone is used for command-channel decoding,
because it ensures constant drive level to the tone filters, and thus provides a
constant bandwidth in the decoding process.

In order to increase the security of the command system, the receiver uses
an RF-actuated squelch system, and also a tone-actuated squelch system so

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2. Instruction Manual, IB-42-30-015, RF Link Devices, Receiver Unit 810-
   055-01, Repco Inc., Orlando, FL.

that both RF signals and the proper audio tone must be received before the receiver provides an audio output to the command decoder. All active audio filters were designed with the aid of applications notes.[3,4,5] These circuits are depicted on the schematic diagram shown in Figure 6.

4.4 Command Decoder

The command decoder receives the audio tones from the command receiver, and transforms the tone combinations into 18 different channel outputs that are relay ground closures. This command decoder BCS-18A was developed under In-House Work Unit 76591201.[6] The command channels that control the operation of the repeater are shown in Table 3.

Table 3. Command Function Listing

CH1 or CH10	Power ON
CH2 or CH11	Power OFF
CH3 or CH12	Receiver #1 and Transmitter #1 ON
CH4 or CH13	Receiver #2 ON
CH5 or CH14	Switch receiver audio directly to transmitter
CH6 or CH15	Switch receiver audio to signal conditioner
CH7 or CH16	Select 3107 Hz tone filter output
CH8 or CH17	Select FSK filter output
CH9 or CH18	Transmitter #2 ON

Normally, power is applied only to the command receiver, the command decoder, and the relay control unit and, then, by selecting the proper command channels from ground control, the mode of operation of the repeater can be determined. After the balloon mission, the repeater is turned off by command.

4.5 Relay Control Unit

The relay control unit is shown in Figure 7 and the schematic diagram for it is depicted in Figure 8. K1 through K6 are latching relays. To program the operation of the repeater, the commands which energize the relays have to be issued only momentarily, and the relays will remain in the latched

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3. <u>1979 General Catalog</u>, pp. 4-83 - 4-117, Burr Brown, Tucson, AZ.

4. <u>Applications Note</u>, L144 Programmable, Micro-<u>Power Triple Op Amp.</u>, Siliconix Inc., Santa Clara, CA.

5. Williams, Arthur B., <u>Active Filter Design</u>, Artech House, Inc., Dedham, MA.

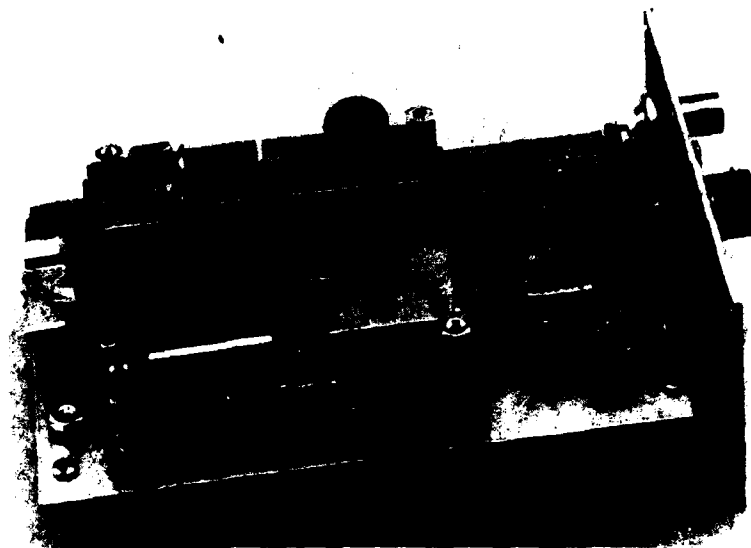6. Laping, Hans (1980) <u>BLS-18A Command Decoder-Selector</u>, AFGL-TR-80-0249, AD A099384.
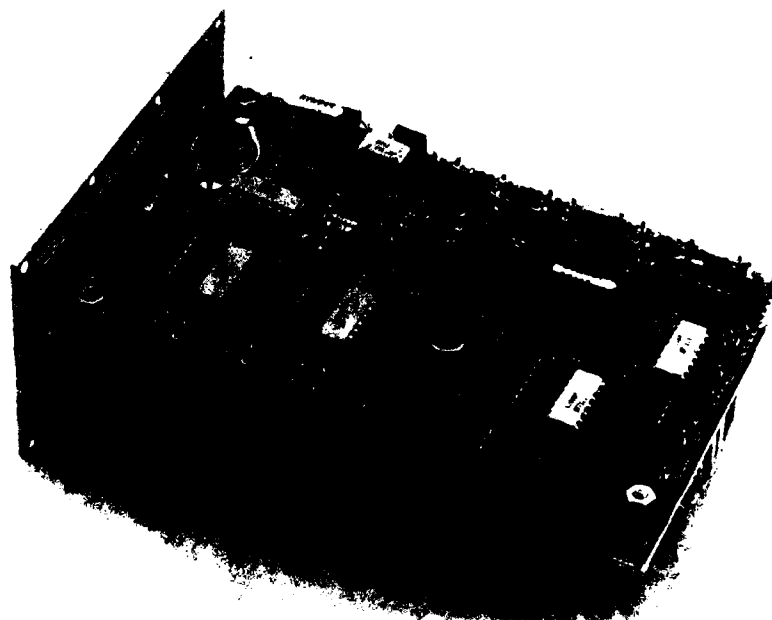
Figure 5a. 140 MHz Command Receiver

Figure 5b. 140 MHz Command Receiver
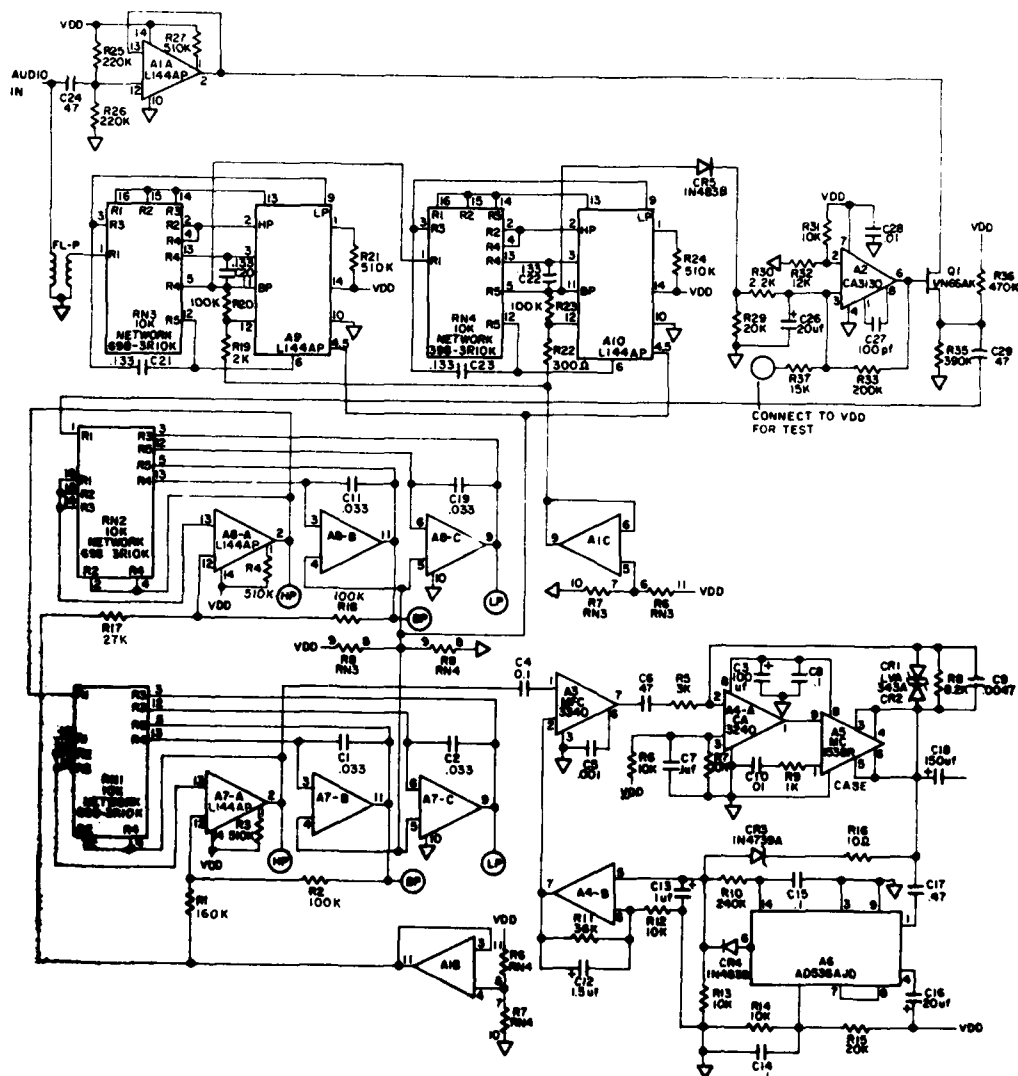(audio filters and AGC circuits shown)

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Figure 6. Schematic of AGC and Audio Filter Circuits for 140 MHz
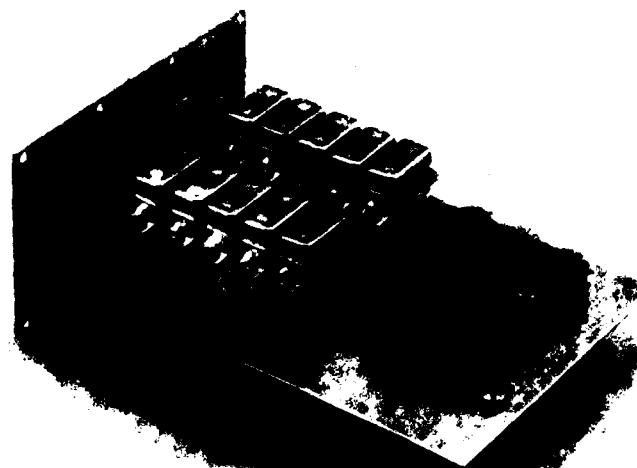Command Receiver

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Figure 7. Relay Control Unit

position until the state is changed by another command closure on the second coil. The potentiometer R1 is used to adjust the audio output when the audio signal is fed directly from one of the 40 MHz receivers to the modulation input of one of the transmitters. It adjusts the deviation of the transmitters.

4.6 Signal Conditioning Unit

The signal conditioning unit is shown in Figure 9, and its schematic is depicted in Figure 10. The main purpose of this unit is to filter out some of the noise that might be received from the balloon's transmitted signals so that the retransmitted signal contains only the original transmission from the balloon.

A1, A2, and A3 are active bandpass filters in cascade that filter a single tone frequency centered at 3107 Hz. The tone is turned on and off according to a slow digital code transmitted from the balloon control package. The diodes between the individual filter sections block out ambient noise that might exist in the received signals so that only the 3107 Hz signal is retransmitted via one of the repeater transmitters. These filters are a derivative of an RC oscillator. The gain of each amplifier is adjusted so that oscillation can never occur.

A5, A6, and A7, with their associated components, form a wider bandpass filter with a center frequency of 2125 Hz. This filter is selected when the balloon telemetry uses frequency-shift keying (FSK) for the digital data transmission. This filter was designed with the aid of applications notes.[3, 4, 5] In this mode the frequency shift between a digital 1 and 0 is 200 Hz that is controlled by a slow-speed modem in the balloon control package.
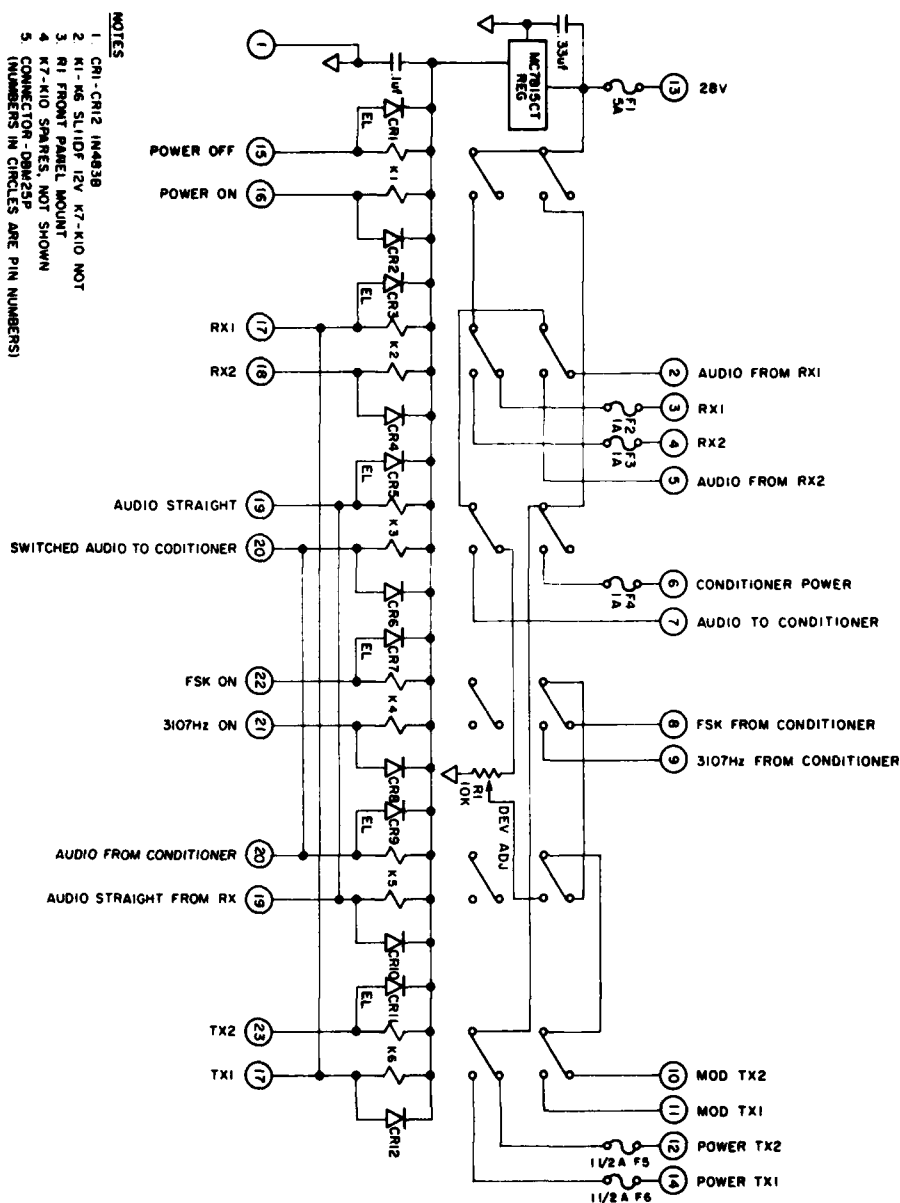
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Figure 8. Schematic of Relay Control Unit

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Figure 9. Signal Conditioning Unit

5. CONCLUSIONS

With the ever-decreasing manpower allocation for scientific balloon flights, this data repeater should be very helpful in extending the line-of-sight range for radio communications without the need for a mobile unit for short- to medium-distance balloon flight operations from Holloman AFB.

The optical line-of-sight tables generated in the beginning of this report can be used as minimum expected radio horizons for very high frequencies (VHF) and higher frequencies. In many instances they can be used as a basis to determine whether or not to deploy a communications van down range. One must always consider, however, the free space attenuation of the radio transmissions from the balloon control package before a final decision is made on the deployment of the communications van. This can be accomplished by applying the formula shown below:

$$\text{Path Loss (db)} = 37.8 + 20\log f + 20\log d$$

where f = frequency in MHz
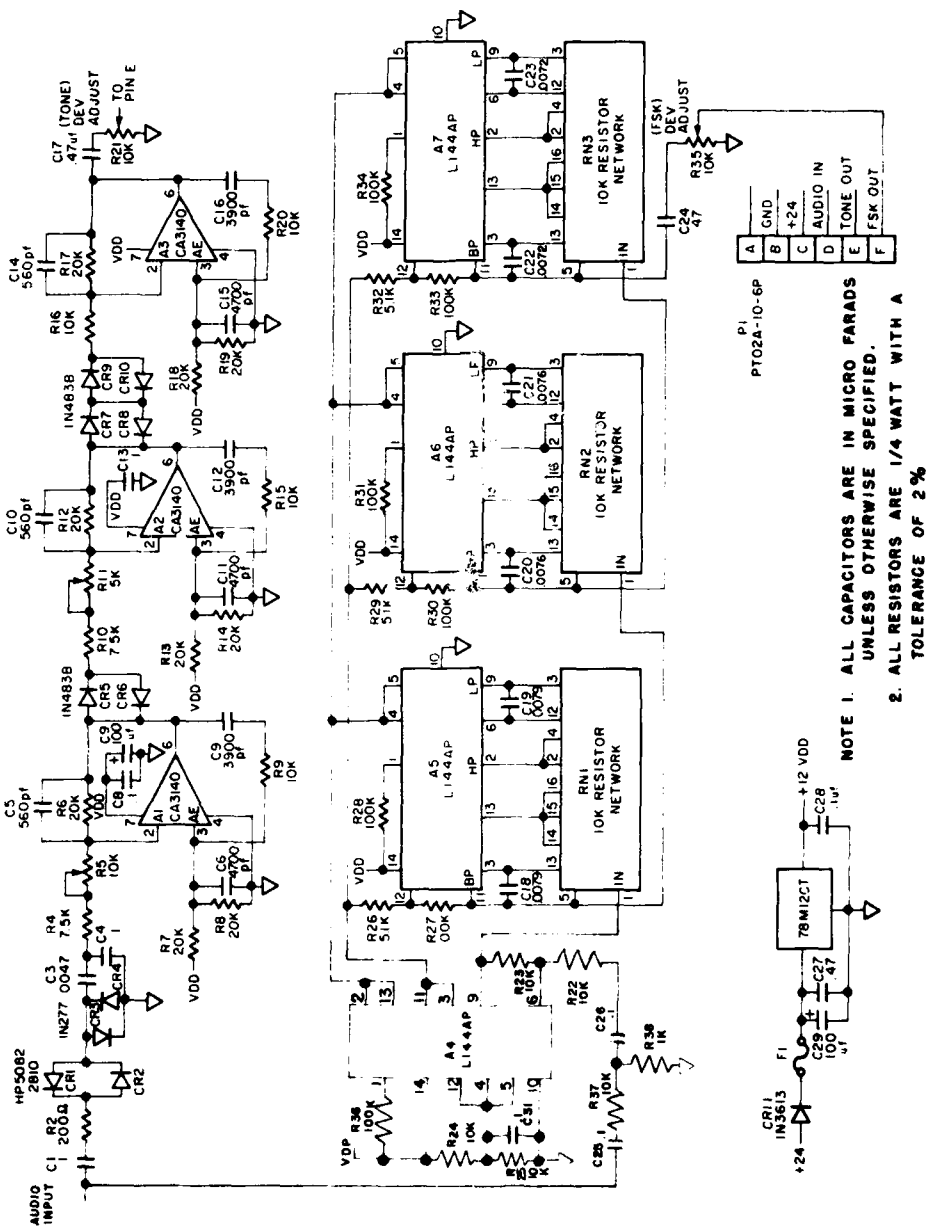d = distance in miles

Figure 10. Schematic of Signal Conditioning Unit in Appendix A

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The radiated power from the transmitter of the balloon control package, and all gains in the receiving system, plus the minimum acceptable signal-to-noise ratio at the receiving end, must be greater than the path loss, otherwise a van must be deployed.

References

1. Instruction Manual, IB-42-30-016, RF Link Devices, Receiver Unit 810-056, Repco Inc., Orlando, FL.

2. Instruction Manual, IB-42-30-015, RF Link Devices, Receiver Unit 810-055-01, Repco Inc., Orlando, FL.

3. 1979 General Catalog, pp. 4-83 - 4-117, Burr Brown, Tuscon, AZ.

4. Application Note, L144 Programmable, Micro-Power Triple Op Amp., Siliconix Inc., Santa Clara, CA.

5. William, Arthur B., Active Filter Design, Artech House, Inc., Dedham, MA.

6. Laping, Hans (1980) BLS-18A Command Decoder-Selector, AFGL-TR-80-0249, AD A099384.
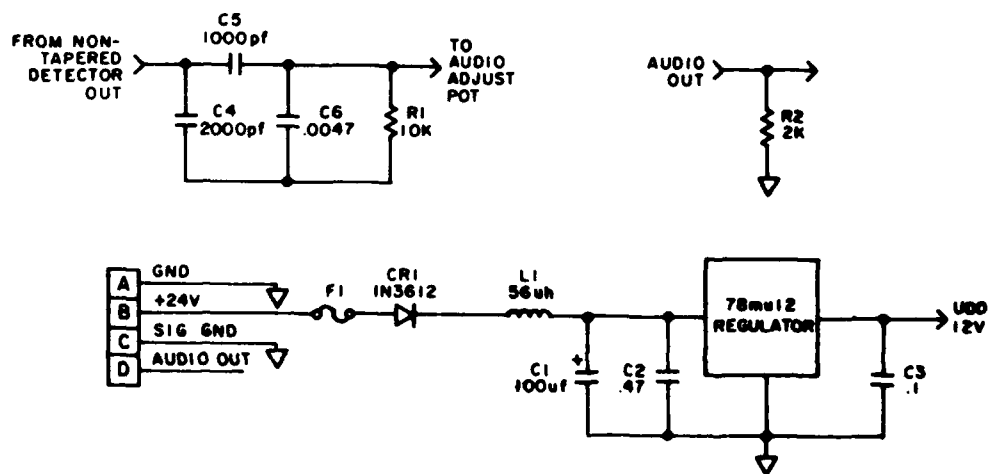
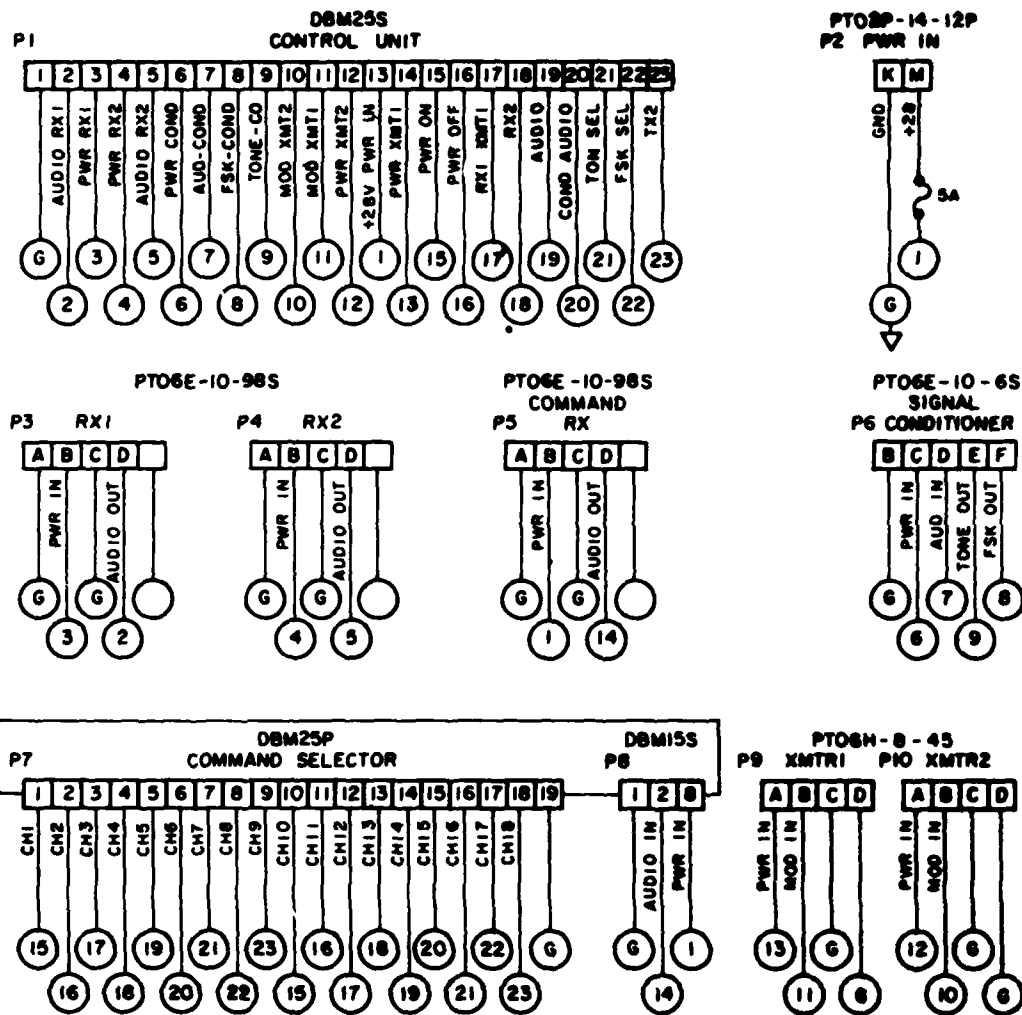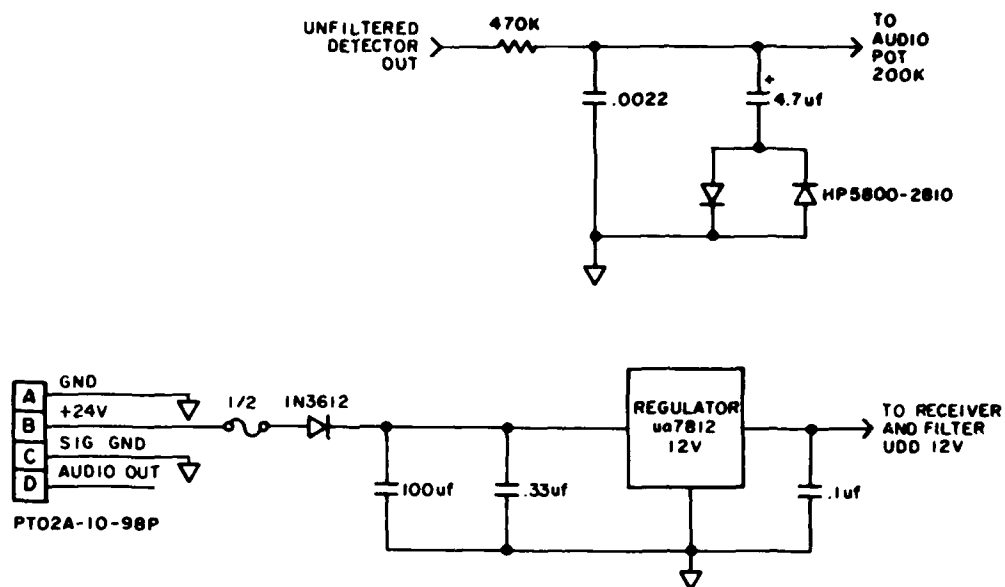Figure A1. 40 MHz Receiver Modification

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Figure A2. Repeater Interwiring Diagram

Figure A3. 140 MHz Receiver Modifications